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FINENESS TEST OF MOLDING SAND

By Margaret Price and Alexander I. Krynitsky

ABSTRACT

It is recognized that the present American Foundrymen's Association sand fineness-test method is not entirely satisfactory since sands with the same AFA classification may have different properties. In view of this fact other methods have been proposed, but in general little was published on this subject. The need for more data has prompted the present investigation. The object of this study was to evaluate the merits of the regular pipette, the Andreasen pipette, and the hydrometer methods in making fineness determinations on Albany and Lumberton molding sands. The hydrometer method which was described in detail in the paper was found to be preferable because it yields satisfactory results conveniently with a minimum expenditure of time for the operator.

CONTENTS

I. INTRODUCTION

At the present time the accepted test for evaluating the clay substance in a molding sand is the American Foundrymen's Association standard sedimentation method. This test is of limited value because the definition of clay substance as a material composed of particles less than 20 microns is rather arbitrary. In addition, the test yields no information on the distribution of the subsieve particles contained in the sand. These limitations are recognized by the AFA,

and according to the Foundry Sand Testing Handbook [1] [1] this method "has as its principal defect the inability to separate fine silt from true clay. This accounts for the fact that two sands with the same AFA clay content may have different properties."

Morey and Taylor [2] have ably demonstrated that the present AFA method does not give an adequate evaluation of molding sand.

As far as it is known to the authors, the first contribution on the subject of determining the size distribution of the subsieve particles in molding sand was presented by Jackson and Saeger [3]. In their pioneer work they used a pipette method and showed that this method was readily adaptable to the determination of the fineness of molding sand. The object of the present investigation was to compare three different methods of making fineness determinations on molding sands.

II. MATERIALS

Albany and Lumberton molding sands were employed in this investigation. The samples were thoroughly mixed, riddled, mulled at a low moisture content, and were stored in mason jars prior to use. The specific gravities of the sands were determined by the standard method for specific gravity of soil [4]. The average values for the specific gravities of Albany and Lumberton sands were found to be 2.698 and 2.676, respectively. The sands tested were dispersed in distilled water, and sodium hydroxide solutions were used as a deflocculating agent.

III. METHODS AND RESULTS

The essential principle of the fineness test methods used in this investigation is sedimentation. When solid particles of various sizes are dispersed in a liquid medium and then allowed to settle freely, a definite relationship exists between the diameter of the particles, the density of the particles, the density of the liquid, the viscosity of the liquid, and the distance that each particle settles in unit time. This relationship is expressed mathematically by Stokes law, which may be written

$$d=\sqrt{\frac{30nL}{980(G-G_1)T}},$$

where

d=maximum diameter of particle in millimeters
n=coefficient of viscosity of the suspending medium in poises. (It varies with changes in temperature of the suspending medium.)
L=depth of settling in centimeters
T=time in minutes (period of sedimentation)
G=specific gravity of sand particles
G_1=specific gravity of the suspending medium.

Although Stokes law applies particularly to spherical particles, Andreasen has shown that it can be applied to angular or cubical particles of the same weight as well [5].

Regular pipette, Andreasen pipette, and hydrometer methods were employed in this investigation.

[1] Figures in brackets indicate the literature references at the end of this paper.

1. PIPETTE METHODS

When solid particles of various sizes are dispersed in a liquid medium and then allowed to settle freely, the relative distances that individual particles will settle in a fixed time depends upon their size providing the particles are of the same density and the temperature remains constant. If a sample is taken from a specified level after a stated time, the concentration of the solid particles in the sample will be less than the original concentration by the weight of the larger particles that have settled out of the test zone. The maximum particle size in the sample can be calculated with the aid of the Stokes formula and if several samples are taken at suitable intervals of time, data may be obtained for plotting a particle size distribution curve for the material undergoing test.

(a) REGULAR PIPETTE METHOD

This method was used by Jackson and Saeger and has been described in detail in their paper [3].

(1) *Experimental details.*—A 50-g sample of oven-dried sand was placed in a 1-qt mason jar with 25 ml of a 1-percent sodium hydroxide solution and 475 ml of distilled water and was dispersed for 5 minutes with an electric stirrer equipped with vertical baffles. The mixture was then transferred into a 1-liter cylinder by repeated washings with distilled water. Additional distilled water was added to bring the volume of the suspension up to 1 liter. The mixture was shaken thoroughly for 1 minute and the cylinder placed on a level surface to allow uniform undisturbed settling. A stop watch was immediately started, and samples were withdrawn at intervals of 2, 5, 15, 30, 60, 250, and 1,440 minutes. The tip of the pipette was inserted in the mixture to a settling depth, L, of 5 in. (12.7 cm). After the sample had been withdrawn, the pipette was rinsed with distilled water and the rinsings added to the sample in a weighed evaporating dish. The temperature of the mixture was determined at the time that each sample was withdrawn.

The samples were evaporated to dryness in an oven at 105° C, cooled in a desiccator, and weighed for the determination of solids. The weight of each dried sample was corrected for the amount of NaOH in the sample. This correction could not be based on the calculated concentration of NaOH in the sample but had to be determined experimentally. It was found to be −0.0095 g for each sample. The percentage of particles remaining in suspension at the time—the sample was taken was determined from the simple formula

$$P=\frac{W_1-0.0095}{W}\times 100,$$

where

W_1=weight of dried sample

W=weight of sand originally dispersed in 25 ml (since 50 g was dispersed in 1,000 ml and a 25-ml sample was withdrawn, $W=(50\times 25)/1000=1.25$ g).

The maximum particle size in each sample was calculated from Stokes law by substituting in the correct values for time, temperature, settling depth, specific gravity of the sand, etc. This computation was simplified considerably by the use of a nomographic chart such as that used by Jackson and Saeger. This nomograph was constructed for use with a sand having a specific gravity of 2.650. As the specific gravities of the sands used were slightly higher than this value (Albany, 2.698; Lumberton, 2.676) a correction for this difference was made. This correction was calculated from the simple relationship derived from the Stokes formula

$$\text{Specific gravity correction}=\sqrt{\frac{1.65}{\text{sp gr}-1}}$$

when sp gr is the specific gravity of the sand. For each of the sands used the correction factor amounted to 0.99. This factor multiplied by the diameter obtained from the nomograph gives the true value of d. Obviously, this correction is very small and need not be made except when extreme accuracy is required.

After the last sample was withdrawn the mixture remaining in the cylinder was wet screened on a No. 270 United States Standard Sieve under a light stream of tap water for 5 minutes and then oven-dried on the same screen. The dried sample was removed from the screen, weighed, sieved, and the weights of the fractions collected on each individual sieve were determined in the usual way.

The complete distribution of particle sizes as determined both by the sieving test and by the pipette determination is represented most conveniently by a cumulative curve. The accumulated amount expressed in percent that would be retained on each successively finer sieve is plotted against the diameter of the sieve opening on a semilogarithmic graph paper. The percentage in each case refers to the particles coarser than the specified size. In the subsieve range the data obtained by the pipette method specifies the percentage, P, of the test sample representing particles finer than a specified diameter. Therefore, the value, $100\%-P$ represents the fraction of particles coarser than the specified size in each instance.

(2) *Results obtained.*—Three determinations were made by the regular pipette method on both the Albany and the Lumberton sands. The data were tabulated and cumulative curves were plotted. A sample data sheet showing the results obtained in one of these tests is presented in tables 1 and 2. The cumulative curves related to the regular pipette tests are shown in figures 1 and 2.

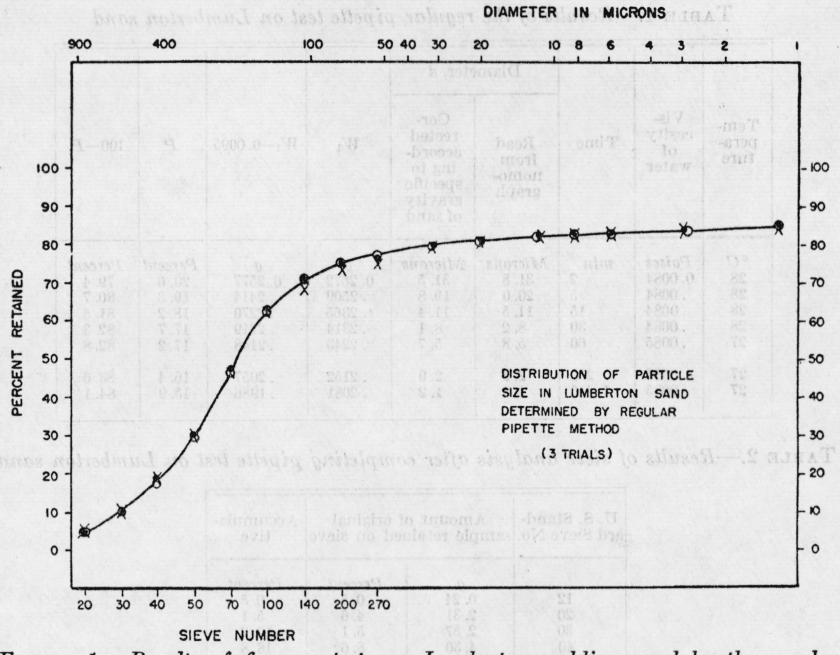

FIGURE 1.—*Results of fineness tests on Lumberton molding sand by the regular pipette method.*

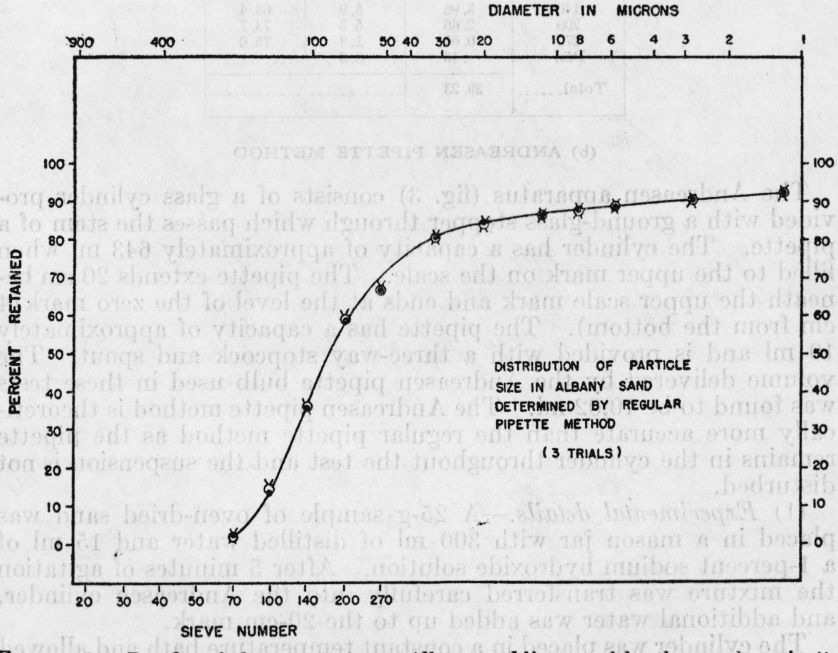

FIGURE 2.—*Results of fineness tests on Albany molding sand by the regular pipette method.*

TABLE 1.—*Results of the regular pipette test on Lumberton sand*

Temperature	Viscosity of water	Time	Diameter, d		W_1	$W_1-0.0095$	P	$100-P$
			Read from nomograph	Corrected according to specific gravity of sand				
°C	Poises	min	Microns	Microns	g	g	Percent	Percent
28	0.0084	2	31.8	31.5	0.2672	0.2577	20.6	79.4
28	.0084	5	20.0	19.8	.2509	.2414	19.3	80.7
28	.0084	15	11.5	11.4	.2365	.2270	18.2	81.8
28	.0084	30	8.2	8.1	.2314	.2219	17.7	82.3
27	.0085	60	5.8	5.7	.2243	.2148	17.2	82.8
27	.0085	250	2.9	2.9	.2152	.2057	16.4	83.6
27	.0085	1,440	1.2	1.2	.2081	.1986	15.9	84.1

TABLE 2.—*Results of sieve analysis after completing pipette test on Lumberton sand*

U. S. Standard Sieve No.	Amount of original sample retained on sieve		Accumulative
	g	Percent	Percent
12	0.24	0.5	0.5
20	2.31	4.6	5.1
30	2.57	5.1	10.2
40	4.30	8.6	18.8
50	5.60	11.2	30.0
70	8.24	16.5	46.5
100	8.01	16.0	62.5
140	3.96	5.9	68.4
200	2.66	5.3	73.7
270	0.66	1.3	75.0
Pan	.16	0.3	----------
Total	39.23	----------	----------

(b) ANDREASEN PIPETTE METHOD

The Andreasen apparatus (fig. 3) consists of a glass cylinder provided with a ground-glass stopper through which passes the stem of a pipette. The cylinder has a capacity of approximately 643 ml when filled to the upper mark on the scale. The pipette extends 20 cm beneath the upper scale mark and ends at the level of the zero mark (4 cm from the bottom). The pipette has a capacity of approximately 10 ml and is provided with a three-way stopcock and spout. The volume delivered by the Andreasen pipette bulb used in these tests was found to be 10.02 ml. The Andreasen pipette method is theoretically more accurate than the regular pipette method as the pipette remains in the cylinder throughout the test and the suspension is not disturbed.

(1) *Experimental details.*—A 25-g sample of oven-dried sand was placed in a mason jar with 300 ml of distilled water and 15 ml of a 1-percent sodium hydroxide solution. After 5 minutes of agitation the mixture was transferred carefully into the Andreasen cylinder, and additional water was added up to the 20-cm mark.

The cylinder was placed in a constant temperature bath and allowed to remain there until the mixture reached the required temperature

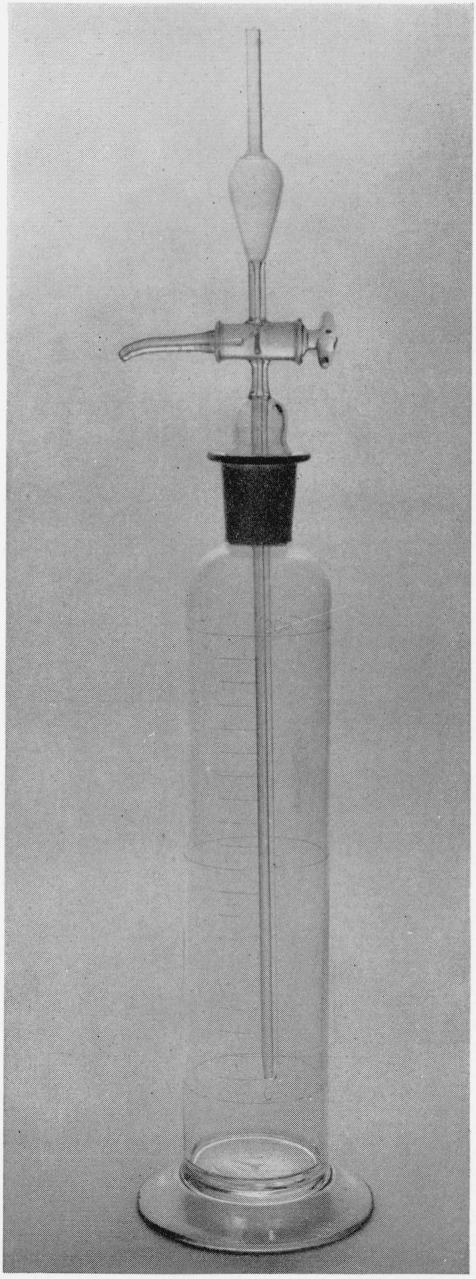

FIGURE 3.—*Andreasen pipette.*

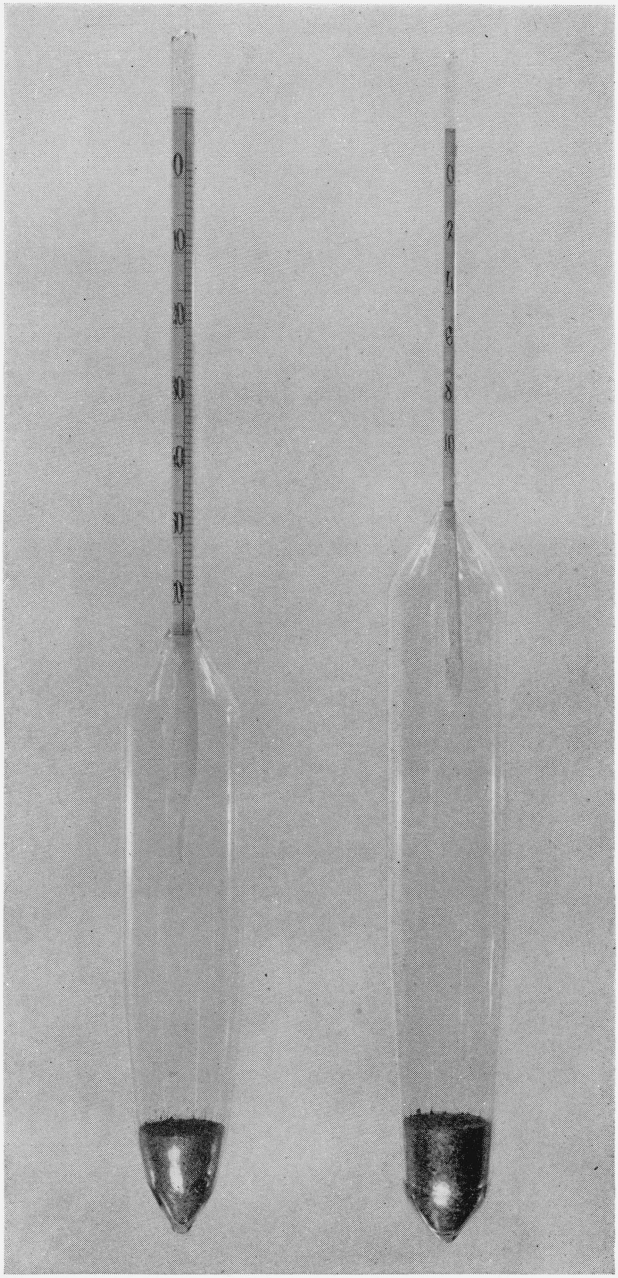

FIGURE 6.—*Gram concentration hydrometers.*

(67° F). The cylinder was then removed from the water bath, and with the stopper in place, the mixture was shaken for 1 minute. Immediately after this operation the cylinder was returned to the constant temperature bath and a stop watch started. Samples were then withdrawn at specified time intervals and placed in an evaporating dish just as in the regular pipette method. The bulb of the pipette was rinsed with distilled water, and these rinsings were added to the sample in the evaporating dish. Each sample was then evaporated to dryness, cooled, and weighed. The weight of each dried sample was corrected for the amount of sodium hydroxide in the sample, which was determined experimentally to be −0.0031 g.

The percentage of material still in suspension was obtained by considering the weight of solids in the sample as compared with the amount in a similar volume immediately after the sand was dispersed. As 25 g of sand was dispersed in a volume of 643 ml, the amount of sand in 10.02 ml was

$$\frac{25}{643}\times 10.02 = 0.389 \text{ g.}$$

The percentage of material in suspension was obtained from the formula

$$P = \frac{W_1 - 0.0031}{W} \times 100,$$

as was shown in the discussion of the regular pipette method.

The maximum diameter of the particles remaining in suspension at the time the sample was taken was calculated from Stokes, formula consideration being given to the fact that the level of the suspension changes after each withdrawal.

The mixture remaining in the pipette cylinder after the last (1,440 minutes) sample was withdrawn was washed on a No. 270 sieve for 5 minutes, dried, and sieved in the usual manner. The cumulative curve was then plotted as described previously.

(2) *Results obtained.*—A sample data sheet showing the results obtained in one of the Andreasen pipette tests is given in tables 3 and 4, and the cumulative curves are presented on figures 4 and 5.

TABLE 3.—*Results of the Andreasen pipette test on Lumberton sand*

Time	L	d	W_1	$W_1-0.0031$	P	$100-P$
min	*cm*	*Microns*	*g*	*g*	*Percent*	*Percent*
2	20.00	43.1	0.0861	0.0830	21.2	78.8
5	19.65	27.0	.0808	.0777	20.0	80.0
15	19.30	15.5	.0760	.0759	19.5	80.5
30	18.95	10.8	.0726	.0693	17.9	82.1
60	18.60	7.6	.0712	.0681	17.5	82.5
250	18.25	3.7	.0681	.0650	16.7	83.3
1,440	17.90	1.5	.0644	.0613	15.8	84.2

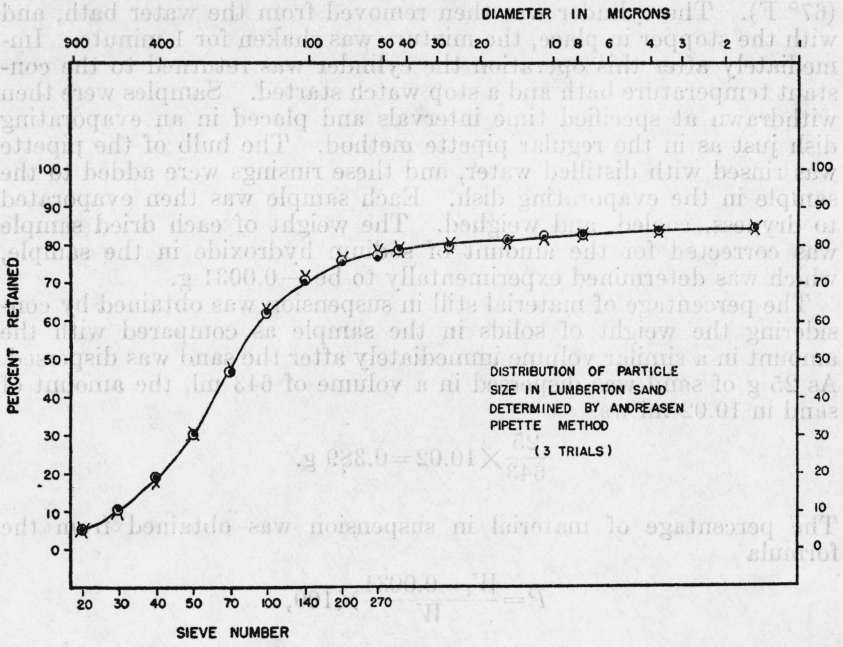

FIGURE 4.—*Results of fineness tests on Lumberton molding sand by the Andreasen pipette method.*

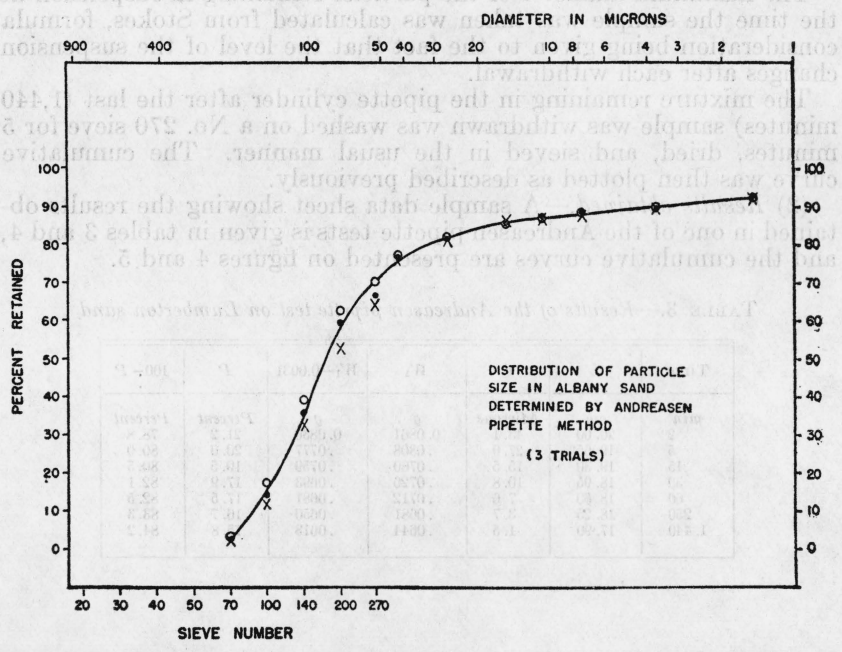

FIGURE 5.—*Results of fineness tests on Albany molding sand by the Andreasen pipette method.*

TABLE 4.—*Results of sieve analysis after completing Andreasen pipette test on Lumberton sand*

Sieve No.	Amount of orig. sample retained on sieve		Accumulated
	g	*Percent*	*Percent*
12	0.10	0.4	0.4
20	1.24	5.0	5.4
30	1.27	5.1	10.5
40	1.94	7.8	18.3
50	3.16	12.6	30.9
70	4.28	17.1	48.0
100	3.83	15.3	63.3
140	2.00	8.3	71.6
200	1.18	4.7	76.3
270	0.51	2.0	78.3
Pan	.14	0.6	----------
Total	19.67	----------	----------

2. HYDROMETER METHOD

The hydrometer method as a means of making fineness determinations of soils was introduced by Bouyoucos [6] in 1927. The procedure is relatively simple and consists in making hydrometer readings on a suspension of the sand in question at predetermined intervals of time. Both the settling depth and the percentage of material in suspension can be obtained from the hydrometer reading. It should be pointed out that in a suspension containing particles of various sizes, a density gradient will develop during settling. Consequently, a hydrometer that measures the specific gravity of the suspension will give a reading that represents the average specific gravity, and therefore the average composition of the vertical zone occupied by the bulb. The settling depth depends on the distance from the surface of the suspension to the center of buoyancy of the hydrometer and this distance changes during the course of a determination. The method of calibrating the hydrometer for evaluating the settling depths for different scale readings will be discussed later.

The standard equipment consists of a hydrometer and a glass cylinder 18 in. in height and 2.34 in. (5.85 cm) in diameter and graduated for a volume of 1,000 ml. Two types of hydrometers are available for this work, (1) a concentration hydrometer, graduated in grams of soil or sand per liter, and (2) a specific-gravity hydrometer. In the present work, all the hydrometer tests were made with the gram-concentration hydrometer.

(a) EXPERIMENTAL DETAILS

A 50-g sample of oven-dried sand was placed in a 1 qt. mason jar with 25 ml of a 3 percent sodium hydroxide solution and 475 ml of distilled water and dispersed for 5 minutes with an electric stirrer equipped with vertical baffles. The mixture was then transferred carefully into the liter cylinder. Additional distilled water was added until the level of the mixture reached the liter mark on the cylinder. The cylinder was placed in a constant-temperature bath and allowed to remain there until the mixture reached the required temperature (67° F). The cylinder was then removed from the

water bath, and with the top closed by the palm of the operator's hand, the mixture was thoroughly shaken for 1 minute by turning the cylinder end over end. Immediately after this operation the cylinder was returned to the constant temperature bath and a stop watch started. Successive hydrometer readings were taken at the top of the meniscus at the same time intervals as in the pipette tests. After each reading the hydrometer was removed from the mixture, cleaned, and placed in a distilled water container in the constant temperature bath until the time for the next reading. This removal was necessary to permit free settling of the suspension and to prevent adherence of the particles to the hydrometer.

(1) *Determination of the maximum diameter of sand particles in the sampling zone.*—The computation of results involves two separate operations: (1) the determination of the maximum size of the particles in suspension, and (2) the determination of the percentage of dispersed particles remaining in suspension at a given time. The settling depth in the hydrometer determination depends on the dimensions of the hydrometer and upon the level at which it comes to rest in a given suspension.

The effective depth of immersion of the hydrometer at any sedimentation time was defined by Schuhmann [7] as the depth of the center of volume of the hydrometer bulb, as it would be measured from the liquid surface with the hydrometer absent. Thus, the evaluation of this depth for any hydrometer reading requires data as to volume and dimensions of the hydrometer and the cross-sectional area of the container used. Computation of the effective depth of settling are given by Klein [8] and Schuhmann [7] as follows:

$$H=H_1+1/2\left(h-\frac{V}{A}\right),$$

where

H = effective depth of immersion
H_1 = distance between the suspension level and the top of the hydrometer bulb
h = length of the hydrometer bulb
V = volume of the hydrometer bulb
A = cross sectional area of container.

The term $\left(-1/2\frac{V}{A}\right)$ is a correction for the change in the distance from the surface of the suspension to the center of the sampling zone when the hydrometer is removed from the suspension. The distance from the surface of the suspension to the center of volume is a true settling depth only when the hydrometer is in the suspension. It may be seen that the hydrometer bulb is here assumed to be of a symmetrical shape, and the center of its volume is taken at the midpoint of the bulb. Actually, the hydrometer bulbs are seldom symmetrical (fig. 6), and therefore the center of volume has to be determined experimentally.

The following method [9] for locating the center of volume was used for this purpose in the present investigation. A graduated cylinder was filled with water and the volume of water recorded.

The hydrometer was then immersed in steps (usually 2 cm) and the water level at each step recorded. The volume readings were plotted against corresponding depth of immersion readings and a "depth of immersion versus volume" curve was drawn. The center of volume of a given hydrometer was determined as a point on this curve, corresponding to one-half the total volume of water displaced by the hydrometer.

The method for locating the center of volume of one of the hydrometers is shown by a curve (fig. 7).

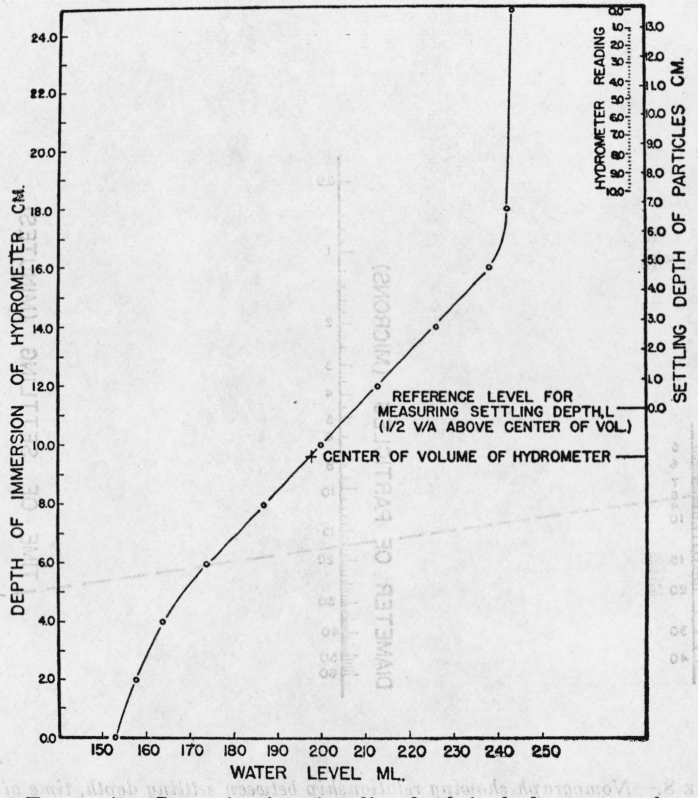

FIGURE 7.—*Determination of settling depth for hydrometer used.*

If we let l represent the distance from the surface of the suspension to the center or volume as determined in this manner, and L, the effective depth of settling, the following relationship will hold:

$$L = l - \frac{V}{2A},$$

where V is the volume of the hydrometer bulb, and A is the cross-sectional area of the container.

In the example (fig. 7) discussed above, $V=89$ ml (for the particular hydrometer used) and $A=27.03$ cm.[2] Hence

$$L=l-1.65 \text{ cm}.$$

This correction of -1.65 cm is incorporated into the scale at the right of figure 7, so that values for L may be obtained directly from

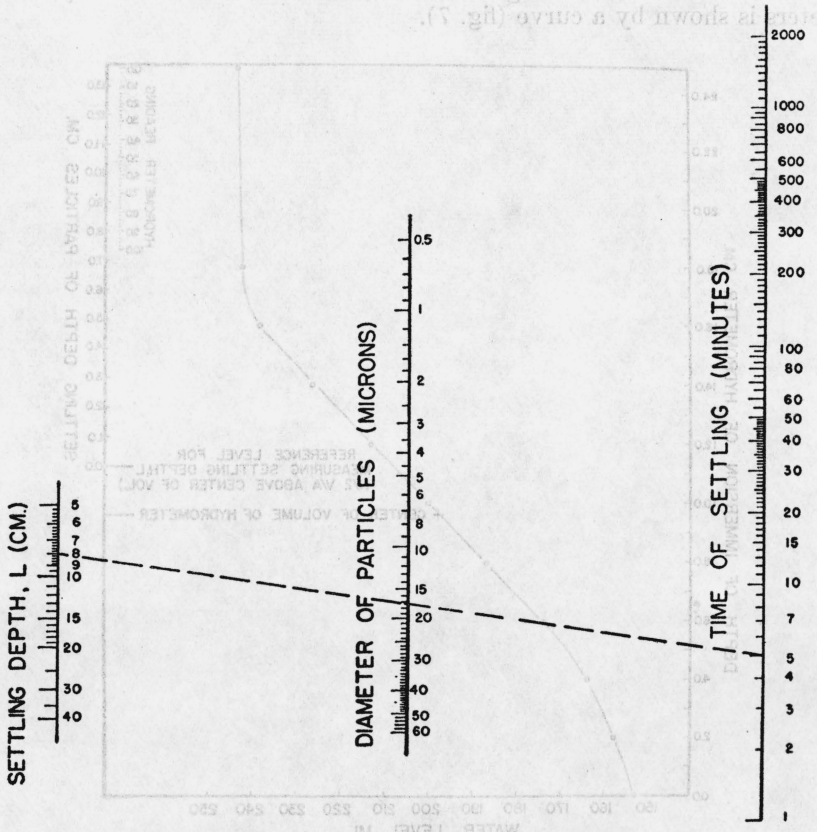

FIGURE 8.—*Nomograph showing relationship between settling depth, time of settling, and particle diameter of sand for hydrometer tests conducted at 67° F on sand with specific gravity assumed to be 2.65.*

the hydrometer readings. For example, for a hydrometer reading of 2.6, L is 12.0 cm; for a reading of 9, the L distance is 8.0 cm, etc.

Knowing the settling depth, L, one can calculate the maximum grain diameter according to Stokes formula given above.

In order to simplify the computation of the maximum diameter of particles present at a distance, L, from the surface, the nomograph shown in figure 8 may be employed. This nomograph furnishes a convenient means for determining the interrelation of time of settling, T (minutes), distance, L (centimeters) and particle diameter, d, (microns). A straight line across the three branches of the nomo-

graph indicates the above interrelation. For example, the broken line in figure 8 shows that after 5 minutes at a settling depth of 8 cm, the suspension at that depth will be free from all particles larger than 17 microns in maximum diameter.

It should be noted that in constructing this nomograph, it was assumed that the test was carried out at the constant temperature of 67° F and that the specific gravity of the sand was 2.65. As the specific gravities of the sands used were somewhat different from this value, the maximum diameters, d, should be corrected as was explained above (with reference to the regular pipette test).

(2) *Determination of the percentage of dispersed sand particles remaining in suspension.*—For the gram concentration hydrometer the percentages of dispersed sand in suspensions corresponding to different hydrometer readings are calculated according to the following formula [10]:

$$P=\frac{(R\pm\Delta R)a}{W}\times 100,$$

where

P=percentage of originally dispersed sand remaining in suspension at a distance, L, below the surface.

R=corrected hydrometer reading. (Before substituting R in this formula, it was necessary to correct for the sodium hydroxide that was used as deflocculating agent for the suspension. This correction was calculated and also checked experimentally and found to be −1.4 when 25 ml of a 3-percent sodium hydroxide solution was present in 1 liter.)

ΔR=Temperature correction for hydrometer reading. For a temperature of 67°F this correction is zero.

W=Weight in grams of oven-dried sand originally dispersed. (This weight is usually 50 g.)

a=Constant depending on the specific gravity of the sand particles.

The values a when referred to different values of the specific gravity of soil or sand particles, G, are given in table 5 [10]. It is sufficiently accurate for ordinary sand tests to select a value for a for the specific gravity nearest to that of the particular sand tested. For both the Albany and Lumberton sands this value was 0.99. Therefore,

$$P=\frac{0.99R}{50}\times 100=1.98R$$

where

P=percentage of originally dispersed sand remaining in suspension at a distance, L, below the surface.

R=corrected hydrometer reading.

TABLE 5.—*Values [10] of constant a*

Specific gravity of sand, G	Constant a
2.95	0.94
2.85	.96
2.75	.98
2.65	1.00
2.55	1.02
2.45	1.05
2.35	1.08

(b) RESULTS OBTAINED

Three tests were run on each of the two molding sands. Cumulative curves for these tests are shown in figures 9 and 10. A sample data sheet giving in detail the results obtained in one of the hydrometer tests is presented in tables 6 and 7. The scale of the hydrometer used in these tests was calibrated and a suitable correction was made (see appendix).

TABLE 6.—*Results of a hydrometer test on Lumberton sand*

Time	Reading	Scale correction	Electrolyte correction	Reading, corrected	"L"	Diameter, d		P	$100-P$
						Read from nomograph	Corrected according to specific gravity of sand		
min					*cm*	*Micron*	*Micron*	*Percent*	*Percent*
2	11.6	−0.9	−1.4	9.3	6.4	25.4	25.1	18.4	81.6
5	11.1	−1.0	−1.4	8.7	6.7	16.3	16.1	17.2	82.8
15	10.6	−1.0	−1.4	8.2	7.0	9.4	9.3	16.3	83.7
30	10.4	−1.0	−1.4	8.0	7.1	6.7	6.6	15.9	84.1
60	10.0	−1.0	−1.4	7.6	7.4	4.8	4.8	15.0	85.0
250	9.7	−1.0	−1.4	7.3	7.6	2.3	2.3	14.5	85.5
1,440	9.4	−1.0	−1.4	7.0	7.8	1.0	1.0	13.9	86.1

TABLE 7.—*Results of sieve analysis after completing hydrometer test on Lumberton sand*

Sieve No.	Amount of original sample retained on sieve		Accumulative
	g	*Percent*	*Percent*
12	0.23	0.5	0.5
20	2.14	4.3	4.8
30	2.57	5.1	9.9
40	3.78	7.6	17.5
50	6.06	12.1	29.6
70	8.77	17.5	47.1
100	7.79	15.6	62.7
140	4.17	8.3	71.0
200	2.41	4.8	75.8
270	0.99	2.0	77.8
Pan	.47	0.9	----------
Total	39.46	----------	----------

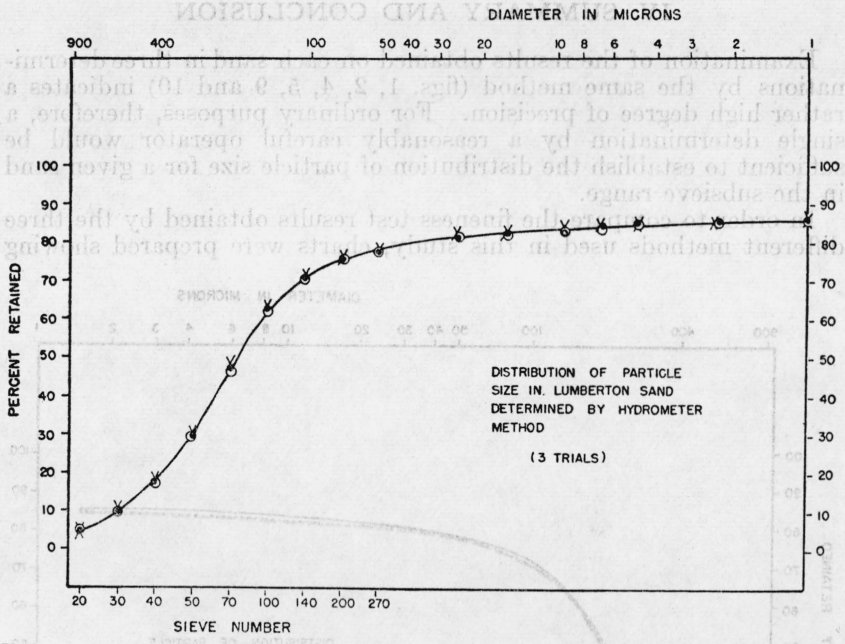

FIGURE 9.—*Results of fineness tests on Lumberton molding sand by the hydrometer method.*

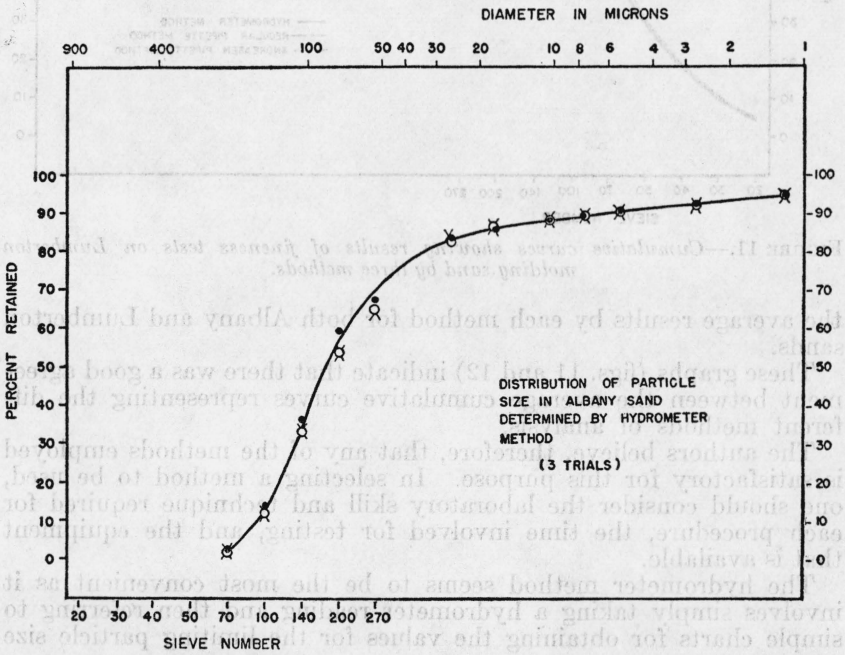

FIGURE 10.—*Results of fineness tests on Albany molding sand by the hydrometer method.*

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IV. SUMMARY AND CONCLUSION

Examination of the results obtained on each sand in three determinations by the same method (figs. 1, 2, 4, 5, 9 and 10) indicates a rather high degree of precision. For ordinary purposes, therefore, a single determination by a reasonably careful operator would be sufficient to establish the distribution of particle size for a given sand in the subsieve range.

In order to compare the fineness test results obtained by the three different methods used in this study, charts were prepared showing

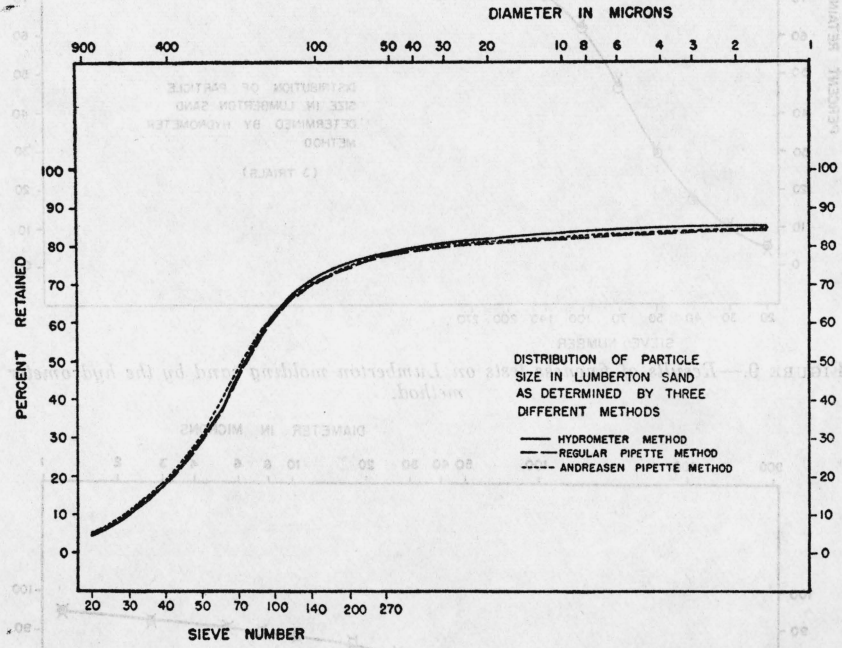

FIGURE 11.—*Cumulative curves showing results of fineness tests on Lumberton molding sand by three methods.*

the average results by each method for both Albany and Lumberton sands.

These graphs (figs. 11 and 12) indicate that there was a good agreement between the average cumulative curves representing the different methods of analysis.

The authors believe, therefore, that any of the methods employed is satisfactory for this purpose. In selecting a method to be used, one should consider the laboratory skill and technique required for each procedure, the time involved for testing, and the equipment that is available.

The hydrometer method seems to be the most convenient as it involves simply taking a hydrometer reading and then referring to simple charts for obtaining the values for the limiting particle size

according to Stokes law, whereas the percentage of material still in suspension is obtained from a simple calculation.

The pipette tests are more time consuming chiefly because of the time required in evaporating, drying, cooling, and weighing. However, in the regular pipette test no special equipment is required other than that which is found in any chemical laboratory.

The Andreasen pipette method, which involves special apparatus, is theoretically more accurate than the regular pipette method as the stem remains in the cylinder throughout the test and the suspension is not disturbed. The fact that the stem of the pipette is stationary,

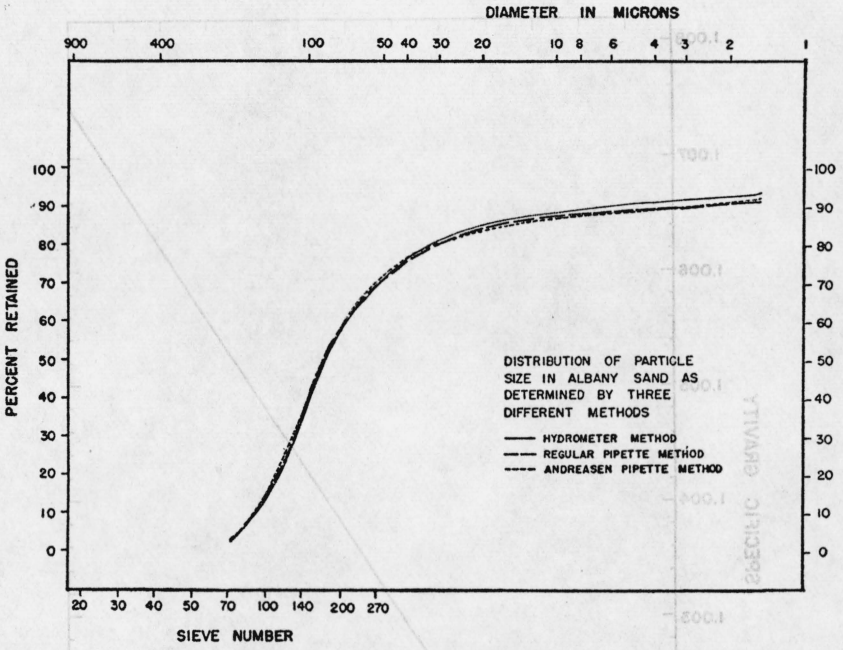

FIGURE 12.—*Cumulative curves showing results of fineness tests on Albany molding sand by three methods.*

however, might appear to introduce an error since some liquid remains in the stem after each sampling and this is always drawn up into the bulb as a part of the next sample. The possible error due to this source would, of course, be quite small. This was demonstrated in a special experiment in which the determination was carried out in the usual manner, except that two samples instead of one were withdrawn after each settling period. The results were in good agreement indicating that no appreciable error was introduced from this source.

Experience with the different methods of determining distribution of particle size in the clay fractions of foundry sands indicates that the hydrometer method is preferable because it yields satisfactory results conveniently in a minimum of time.

V. APPENDIX.—CALIBRATION OF HYDROMETER SCALE

For precise work the scale of each hydrometer should be calibrated. Essentially this involves the testing of the hydrometer in solutions of known specific gravities in the range in which the instrument is to be used. The relationship between the R readings of the gram concentration hydrometer and the corresponding values for specific gravity may be obtained from the formulas [10] that are used for calculating the percentage of material in suspension from readings on the gram concentration hydrometer ($P=[Ra/W]\times 100$) and on the specific gravity hydrometer $\left(P=\frac{1606\ (\text{sp gr}-1)}{W}\frac{a}{}\times 100\right)$. Thus $R=1606\ (\text{sp gr}-1)$.

This relationship between R and specific gravity is shown for a range of values by the graph in figure 13.

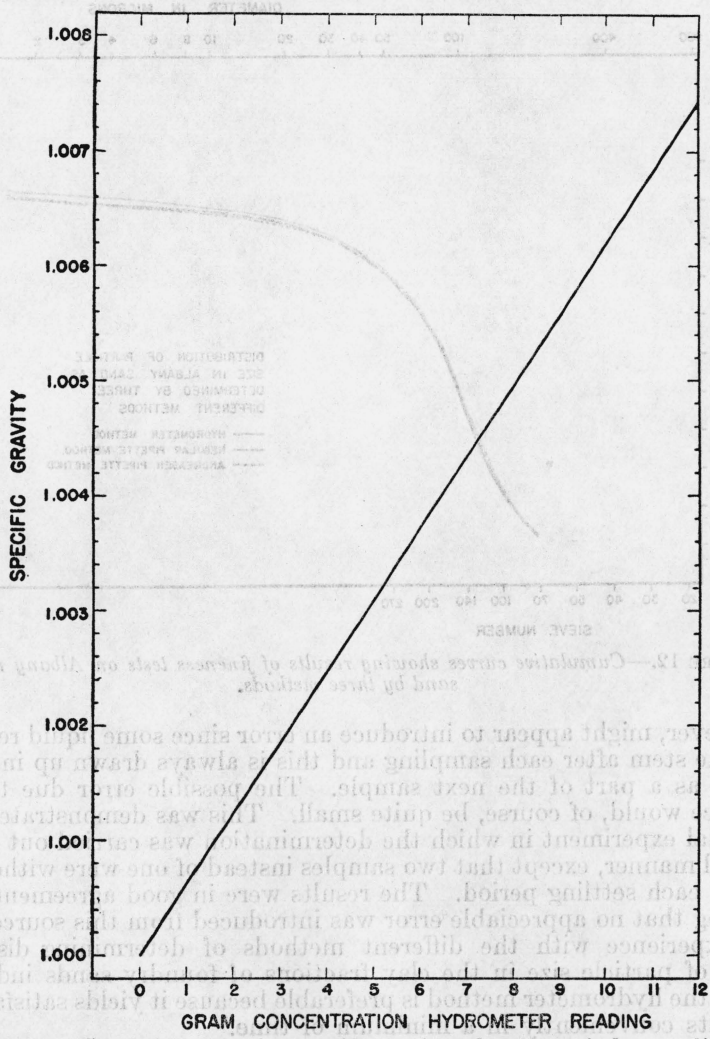

FIGURE 13.—*Graph for converting specific gravity values to equivalent readings on the gram concentration scale.*

Relationship between reading on gram concentration hydrometer and specific gravity. $R=1606\ (\text{sp gr}-1)$.

The zero point of the gram concentration hydrometer may be checked by making a reading in boiled distilled water at 67° F, whereas sodium chloride solutions of known concentrations are suitable for checking other points on the scale.

Density values for aqueous solutions of sodium chloride (1, 2, and 4% NaCl) at 10°, 20°, and 25° C obtained from the International Critical Tables are shown in table 5. From these values, the densities at 67° F (19.4° C) were obtained by interpolation and the corresponding specific gravities were calculated (table 9). The relationship between concentration of sodium chloride and specific gravity at 67° F is shown in figure 14.

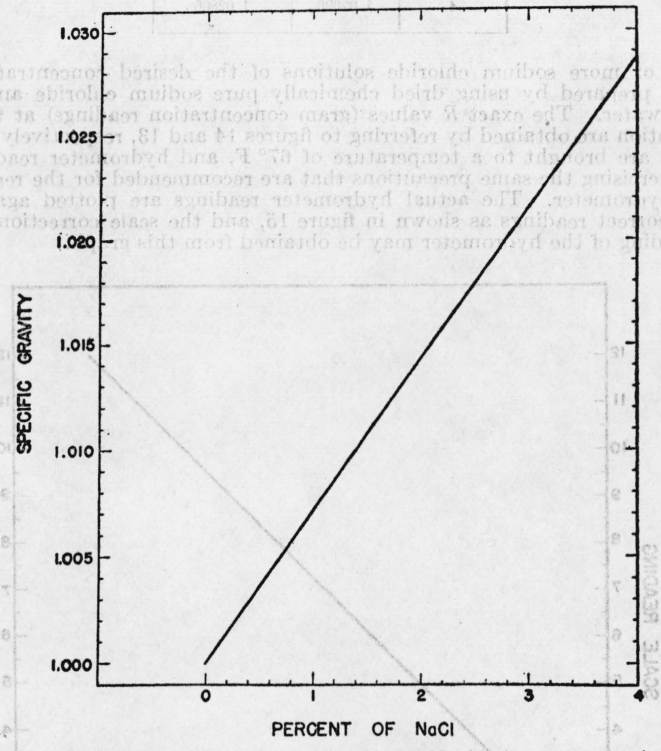

FIGURE 14.—*Specific gravities of acqueous sodium chloride (0 to 4 percent) solutions at 67° F.*

TABLE 8.—*Density values of sodium chloride solutions at different temperatures* [11]

Concentration of NaCl by weight	Density values (g/ml) at—		
	10° C	20° C	25° C
Percent			
1	1.00707	1.00534	1.00409
2	1.01442	1.01246	1.01112
4	1.02920	1.02680	1.02530

TABLE 9.—*Density and specific-gravity values of sodium chloride solutions at 67° F (19.4° C)*

Concentration of NaCl	Densities	Specific gravities (density/0.99835)
Percent		
0	0.99835	1.00000
1	1.00546	1.00712
2	1.01259	1.01426
4	1.02696	1.02866

Three or more sodium chloride solutions of the desired concentrations are carefully prepared by using dried chemically pure sodium chloride and boiled distilled water. The exact R values (gram concentration readings) at 67° F for each solution are obtained by referring to figures 14 and 13, respectively. These solutions are brought to a temperature of 67° F, and hydrometer readings are made, exercising the same precautions that are recommended for the regular use of the hydrometer. The actual hydrometer readings are plotted against the true or correct readings as shown in figure 15, and the scale correction for any scale reading of the hydrometer may be obtained from this graph.

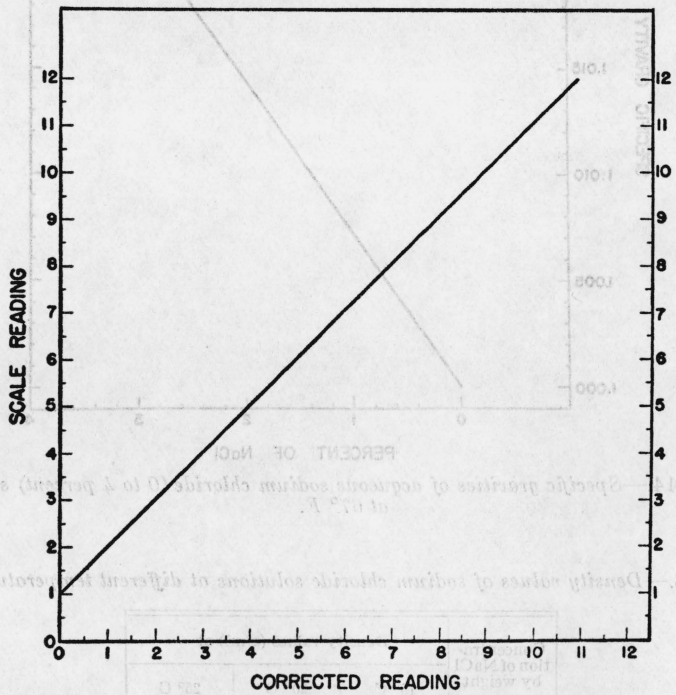

FIGURE 15.—*Graph for obtaining corrected readings from scale readings on gram concentration hydrometer.*

Corrections for hydrometer scale.

Acknowledgement is made to Vernon C. F. Holm for suggestions and assistance and to Lura F. Roehl for preparing the charts and graphs.

VI. REFERENCES

[1] Foundry Sand Testing Handbook, Standards and Tentative Standards adopted by the American Foundrymen's Association, fifth edition, 1944.
[2] Robert E. Morey and Howard F. Taylor, the cumulative curve for foundry sand control, Foundry **73,** No. 8, 98 (August 1945).
[3] Clarence E. Jackson and C. M. Saeger, Jr., Use of the pipette method in the fineness test of molding sand, J. Research NBS **14,** 59 (1935) RP757.
[4] Standard method for specific gravity of soil, method T–100–38, The American Association of State Highway Officials. Standard specifications for highway materials and methods of sampling and testing, p. 315 (1938).
[5] A. H. M. Andreasen, Uber die Gultigkeit des Stokes' schen Gesetzes fur nicht Kugelformige teilchen, Kolloid-Z. **48,** 175 (1929).
[6] G. J. Bouyoucos, The hydrometer use as a new method for the mechanical analysis of soils, Soil Science **23,** 343 (1927).
[7] R. Schuhmann, Jr., Laboratory sizing, Powder Metallurgy **17,** 186 (American Society for Metals, Cleveland, Ohio, 1942).
[8] Alexander Klein, An improved hydrometer for use in fineness determinations, symposium of new methods for particle size determination in the subsieve range, American Society for Testing Materials, p. 52 (March 4, 1941).
[9] Private communication, Courtesy of the U. S. Public Road Laboratory.
[10] Standard method of mechanical analysis of soils, ASTM Designation D 422–39, pages 525–534, ASTM Standards 1942, part II, nonmetalilc materials.
11] Int. Critical Tables **3,** 79 (1928).

WASHINGTON, March 8, 1946.